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United States Department of Agriculture–Agricultural Research Service stored-grain areawide Integrated Pest Management program†‡

Paul W Flinn,[1]* David W Hagstrum,[1] Carl Reed[2] and Tom W Phillips[3]

[1]*Grain Marketing and Production Research Center, USDA, ARS, Manhattan, KS 66502, USA*
[2]*Department of Grain Science and Industry, Kansas State University, Manhattan, KS 66506, USA*
[3]*Department of Entomology and Plant Pathology, Oklahoma State University, Stillwater, OK 74078, USA*

Abstract: The USDA Agricultural Research Service (ARS) funded a demonstration project (1998–2002) for areawide IPM for stored wheat in Kansas and Oklahoma. This project was a collaboration of researchers at the ARS Grain Marketing and Production Research Center in Manhattan, Kansas, Kansas State University, and Oklahoma State University. The project utilized two elevator networks, one in each state, for a total of 28 grain elevators. These elevators stored approximately 31 million bushels of wheat, which is approximately 1.2% of the annual national production. Stored wheat was followed as it moved from farm to the country elevator and finally to the terminal elevator. During this study, thousands of grain samples were taken in concrete elevator silos. Wheat stored at elevators was frequently infested by several insect species, which sometimes reached high numbers and damaged the grain. Fumigation using aluminum phosphide pellets was the main method for managing these insect pests in elevators in the USA. Fumigation decisions tended to be based on past experience with controlling stored-grain insects, or were calendar based. Integrated pest management (IPM) requires sampling and risk benefit analysis. We found that the best sampling method for estimating insect density, without turning the grain from one bin to another, was the vacuum probe sampler. Decision support software, Stored Grain Advisor Pro (SGA Pro) was developed that interprets insect sampling data, and provides grain managers with a risk analysis report detailing which bins are at low, moderate or high risk for insect-caused economic losses. Insect density was predicted up to three months in the future based on current insect density, grain temperature and moisture. Because sampling costs money, there is a trade-off between frequency of sampling and the cost of fumigation. The insect growth model in SGA Pro reduces the need to sample as often, thereby making the program more cost-effective. SGA Pro was validated during the final year of the areawide program. Based on data from 533 bins, SGA Pro accurately predicted which bins were at low, moderate or high risk. Only in two out of 533 bins did SGA Pro incorrectly predict bins as being low risk and, in both cases, insect density was only high (>two insects kg^{-1}) at the surface, which suggested recent immigration. SGA Pro is superior to calendar-based management because it ensures that grain is only treated when insect densities exceed economic thresholds (two insects kg^{-1}). This approach will reduce the frequency of fumigation while maintaining high grain quality. Minimizing the use of fumigant improves worker safety and reduces both control costs and harm to the environment.
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1 INTRODUCTION

Areawide integrated pest management (IPM) involves coordinating pest management programs over a large area to reduce the overall densities of insect pests, and minimizes the risk of initial infestation and reinfestation after insect pests have been controlled.[1–3] Examples of the success of this approach in the USA are citrus protective districts,[4] mosquito abatement districts, the screw-worm and boll weevil eradication programs,[5,6] and the United States Department of Agriculture, Agricultural Research Service (USDA-ARS) projects described in this series of articles.

* Correspondence to: Paul W Flinn, Grain Marketing and Production Research Center, USDA, ARS, Manhattan, KS 66502, USA
E-mail: flinn@gmprc.ksu.edu

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The USA is a world leader in wheat production. Stored-grain insects and molds cause millions of dollars in losses annually in this multi-billion dollar industry. Wheat is stored in large networks of country and terminal elevators, and grain from several million acres ultimately ends up in a few very large terminal elevators. Failure to control insects at a few elevators early on can provide a source of infestation that can infest much larger quantities of grain as it is commingled and moves through the grain marketing network.

Areawide IPM is particularly important for stored grain because insects are moved through the marketing system with the grain.[7,8] Mixing infested grain with uninfested grain can increase the cost of insect pest management. Currently, insect populations are managed at most elevators by calendar-based fumigations. These fumigations do not distinguish between high and low insect densities, and do not optimize the timing of the treatment. Insect problems can be managed much more effectively, and with fewer fumigations, if an areawide IPM program is used to manage insects as the grain moves through the elevator network. An areawide integrated pest management program for stored wheat has been very successful in Australia.[9,10] The benefits of the program were reductions in: insect detection, residual chemical treatments, fumigation failures, and cost of the management program.

From 1998 to 2002, the USDA-ARS funded a demonstration project for areawide IPM for stored wheat in Kansas and Oklahoma. This project involved collaboration between researchers at the ARS Grain Marketing and Production Research Center in Manhattan, Kansas, Kansas State University, and Oklahoma State University. The project utilized two elevator networks, one in each state, for a total of 28 grain elevators. These elevators stored about 31 million bushels of wheat, which is approximately 1.2% of the annual national wheat production. The wheat at these elevators was harvested from over 800 000 acres (324 000 ha). Elevators were chosen for the project so that the wheat could be followed as it moved from farm to the country elevator and finally to the terminal elevator. We also tried to select elevators that had primarily upright concrete storage. Roughly, 70% of the wheat sampled at the 24 country elevators moved to the four terminal elevators that were collaborating in the areawide IPM project.

2 PROJECT OBJECTIVES, EXPERIMENTAL DESIGN AND RESULTS

The first objective of the stored grain areawide IPM project was to establish which methods of monitoring insect pest populations provided the best information for making pest management decisions. Elevator managers have traditionally depended upon thermocouples to alert them of potential mold and insect problems. However, grain heating occurs only when large numbers of insects or severe mold problems are present. Another insect monitoring and grain conditioning practice is to 'turn' the grain from one bin to another, sampling the grain as it moves. However, grain turning is expensive. Fumigation is usually done as the grain is turned; thus, if the manager decides to turn, he often fumigates at the same time to save the cost of turning and fumigating a second time. For the areawide IPM study, we needed a method to monitor insect populations in grain bins without having to turn the grain. We used a vacuum sampling probe to take a 3-kg sample from each 1.3-m grain layer. Initially, we were able to sample only the top 13 m of grain, but the sampling equipment was improved so that we could sample all the way to the bottom of most concrete grain bins (≈33 m). The improvement consisted of switching from steel tubing to aluminum tubing, which was screwed together. A special inclined sieve was designed to separate insects from the grain.[11] In addition to the vacuum sampling, grain temperature and moisture were monitored. Trucks were sampled as grain was received at elevators from farms or other elevators. Samples were taken from the conveyor belts as grain was loaded or unloaded from storage bins. Grain residues inside and outside the bins were sampled for insects. Insect infestations near the bottom of the grain stored in bins were sampled by releasing small amounts of grain from each bin. Pitfall probe traps were used to sample insects near the grain surface.

In the first year of the stored grain areawide project, samples taken as the grain was unloaded from trucks or bins were useful for determining insect density at that point, but were not useful for deciding whether a particular bin needed to be fumigated before the grain was moved. Samples taken with probe traps near the surface or by releasing a small amount of wheat from the bin bottom were representative of only a very small portion of the grain stored in a bin. Data collected with the vacuum probe sampler were highly correlated ($r^2 = 0.79$) with grain samples taken as the bin was unloaded. Thus, the vacuum probe provided the most convenient and reliable method of routinely monitoring bulk grain for insects without having to turn the grain.

In general, insect density was found to decrease with grain depth, and in most cases, the majority of insects were found in the top 13 m of the grain (Fig 1). We found that the time required to vacuum probe a bin was greatly reduced by sampling only the top 13 m of the grain. Using the inclined sieve, samples were sieved at the elevator, and only the fine material containing the insects was transported to the laboratory for identification and counting.

The value of the insect monitoring program to the elevator manager was evaluated by providing the managers with information about the insect density in each of their bins every 60 days. We also evaluated how this information was used by the manager to make pest management decisions. In addition to fumigation,

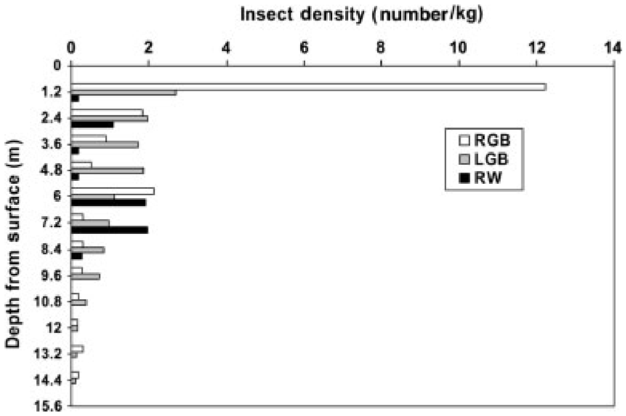

Figure 1. Relationship between sample depth and insect density for rusty grain beetle (RGB), lesser grain borer (LGB) and rice weevil (RW).

other methods, like aeration to cool the grain, can be used instead of fumigation to suppress insect growth in bins with low insect densities (<two insects kg^{-1}).

The second objective was to measure the efficacy of current pest management practices. Elevator managers relied primarily on calendar-scheduled fumigations to manage insect pests. The efficacy of fumigation at two terminal elevators was found to be quite variable. At one elevator, fumigation failed to reduce insect populations by 80% in all of the bins; while in two other elevators, insect populations were reduced by 80% in nearly all bins.

The effectiveness of sanitation programs was also evaluated. Grain residues outside bins were generally picked up before insects could reproduce. Cleaning trash from the bottom of empty bins before filling with new grain helped reduce insect numbers, but did not eliminate the residual insect infestations in the bin bottoms.

The third objective was to determine whether early aeration, using automatic controllers, could reduce the number of bins that needed to be fumigated. Roughly 35% of the elevator grain bins involved with the project were equipped with aeration. Automatic controllers allowed the grain to be cooled as soon as it was binned. These were used to automatically turn on fans when the air temperature was below preset thresholds (24, 18 and 7 °C, for the 1st, 2nd and 3rd cooling cycles, respectively). This allowed grain to be cooled, slowing insect population growth, well before grain is traditionally cooled with aeration in the autumn. Slower insect population growth means that grain may not need to be fumigated. Cooling with automatic aeration is more efficient than manually controlled aeration, and is less expensive than it is to turn and fumigate a bin. In addition, if fumigation is necessary, cooling grain after fumigation greatly reduced the risk of further insect problems. We installed automatic aeration controllers at several facilities. However, because of various logistical problems, such as premature shipment of the aerated grain, or improper use of the aeration controller, we were not able to demonstrate the economic value of early aeration compared with unaerated grain storage.

The fourth objective was to determine whether insect-monitoring-based fumigation was more effective in reducing the risk of economic losses from insect problems than calendar-based fumigation. With calendar-based fumigation, some bins are fumigated too soon, and others are not fumigated soon enough. Newly harvested grain has a very low insect density and does not need to be fumigated. Leaving newly-harvested grain undisturbed as long as possible minimized the blending of infested and uninfested grain within a grain bin. This occurred because the bottom half of the bin usually contained uninfested wheat, while the top of the grain was infested. Blending of grain bins should be done at load-out to reduce introduction of insects into uninfested grain. Sampling bins with a vacuum probe every six weeks ensures that bins are not fumigated unnecessarily, and that bins that have insect densities above economic thresholds (>two insects kg^{-1}) are treated promptly. Sampling at elevators has shown that usually only a few bins have insect densities that justify fumigation. Treating only the bins that require fumigation could reduce the cost of pest management. For example, fumigating all of the bins at an elevator storing 700 000 bushels of wheat would cost $14 000 (includes costs for turning the grain, loss in grain volume and cost of fumigant). However, if the elevator manager knows that only three of these bins have high insect densities, fumigating only these three bins would cost $1400 and the cost of pest management would be reduced by $12 600.

The fifth objective was to develop risk-management software that would interpret insect sampling data, and provide grain managers with a risk analysis report detailing which bins were at high, moderate or low risk for insect-caused economic losses. This software uses rules to evaluate the risk based on current insect density, predicted insect density, grain temperature and grain moisture. Insect density was predicted up to three months in the future based on grain temperature and moisture. The computer models previously developed for farm-stored grain accurately predicted insect growth in elevators.[12,13] Recommendations were provided for each bin, and a bin diagram showed which bins were at low, moderate or high risk (Fig 2). Because grain managers are accustomed to working with bin diagrams, the output was intuitive to them. The risk analysis software was validated during the final year of the areawide program. Based on data from 533 bins, the program accurately predicted which bins were at low, moderate or high risk (insect densities of <2, 2–10 and >10 kg^{-1}, respectively). A low risk rating was given to a bin when the current average insect density was less than 2 kg^{-1}, a high risk rating was given to a bin when the current average insect density was >2 kg^{-1}, and a moderate risk rating was given to a bin when the predicted insect density in 1–2 months was >10 kg^{-1}. Only in two out of 533 bins did the program incorrectly predict bins as being safe, and in

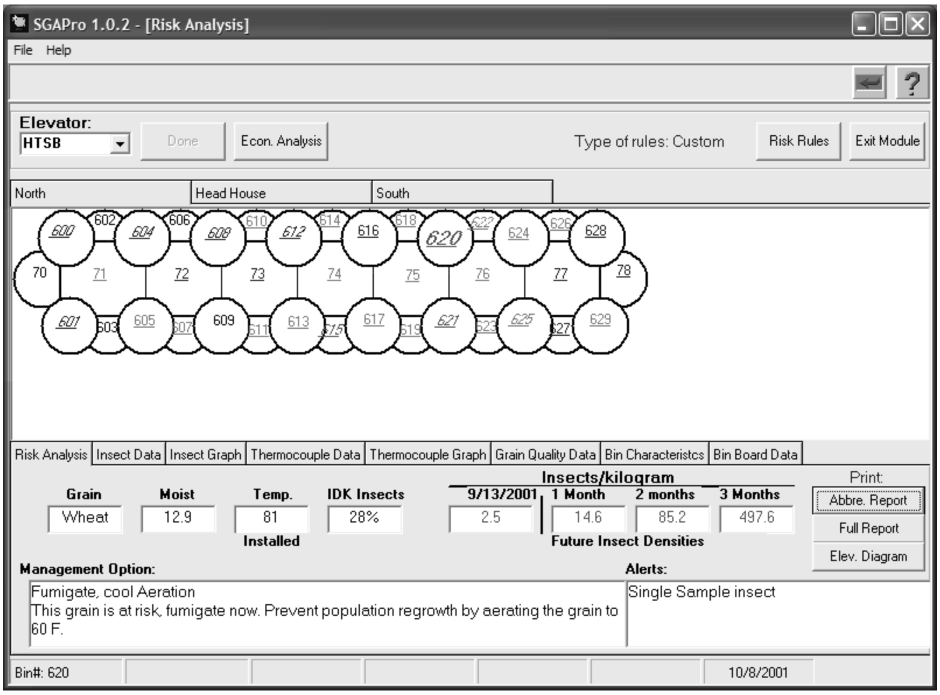

Figure 2. Elevator bin diagram from Stored Grain Advisor Pro; on the computer screen, bins of grain at high, moderate and low risk for insect problems are shown in red, blue and green, respectively. In this figure, bin numbers that are light grey are at low risk, bins 615, 620 and 621 are at high risk, and the rest are at moderate risk. Bin 620 is currently selected and it is at high risk, current insect density is 2.5 kg^{-1}, and should be fumigated.

both cases, insect density was only high in the surface, which suggested recent immigration. The software will be made available to the public in the future at the Grain Marketing and Production Research Center web site: http://bru.usgmrl.ksu.edu.

3 DISCUSSION

Areawide IPM will be adopted by elevator managers only if it is more effective and profitable than their traditional approach, and if it fits into their current marketing practices. Every effort has been made to determine how elevator managers might use insect monitoring information to manage insect problems in their grain bins. The findings of the areawide IPM project have been communicated to managers through nine newsletters, at training programs in Kansas, Oklahoma, Nebraska and Minnesota, and at the National Grain Elevator and Processing Society (GEAPS) annual meetings. When presented with vacuum probe sampling data for their elevators, managers were often surprised at how few bins had insects and how ineffective fumigation could be. Grain managers were very interested in the spatial distribution of insects in their bins and how this could be used to predict insect densities in the blended grain loaded into trucks or railcars. Another accomplishment of the project involved working closely with the vacuum probe manufacturer to improve the sampling equipment. Several modifications were made, including improved connections of the probe segments, a clear window in the cyclone which allowed the operator to see how much grain had been removed, and equipment for pulling probe sections out of the grain after sampling.

4 CONCLUSIONS

Insect-monitoring-based fumigation has several advantages over calendar-based fumigation. Treating bins only when insect densities exceed economic thresholds and treating only those bins that need to be treated can reduce the risk of economic losses from unexpected insect problems while minimizing cost of pest management and the use of fumigant. Minimizing the use of fumigant can improve worker safety. Early aeration can replace fumigation for much of the grain that is stored. Risk analysis software can improve pest management by reducing the frequency of fumigation and predicting when insect pest populations will reach economic injury levels. Improved cost-effectiveness of pest management, while maintaining grain quality, can improve the competitiveness of USA grain in international markets.

Information gathered in this study will be used to develop extension manuals for stored grain IPM. In addition, the risk analysis software will be freely available to the public. Learning to use the software is fairly easy; however, using the sampling equipment and identifying the insects will require some training. We expect that the risk analysis software and sampling protocols developed by this project will be most useful for grain-sampling 'scouting' companies, or used by a trained team within a large grain storage company.

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